

# SDSSJ103913.70+533029.7: A Super Star Cluster in the Outskirts of a Galaxy Merger

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## ABSTRACT

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We describe the serendipitous discovery in the spectroscopic data of the Sloan Digital Sky Survey of a star-like object, SDSSJ103913.70+533029.7, at a heliocentric radial velocity of  $+1012 \text{ km s}^{-1}$ . Its proximity in position and velocity to the spiral galaxy NGC 3310 suggests an association with the galaxy. At this distance, SDSSJ103913.70+533029.7 has the luminosity of a super star cluster and a projected distance of 17 kpc from NGC 3310. Its spectroscopic and photometric properties imply a mass of  $> 10^6 M_{\odot}$  and an age close to that of the tidal shells seen around NGC 3310, suggesting that it formed in the event which formed the shells.

*Subject headings:* galaxies:star clusters–galaxies: individual(NGC 3310)–galaxies:starburst–galaxies:formation

## 1. INTRODUCTION

Super star clusters (van den Bergh 1971; Arp & Sandage 1985; Schweizer 1986; Lançon & Boily 2000; Lamers, Smith & Nota 2004; Gallagher & Smith 2004) are compact (diameters less than 20 pc) high luminosity ( $M_V < -10$ ) clusters whose properties resemble those of globular clusters except that they are young, often much less than 1 Gyr in age. As such, they have importance for our understanding of the formation of globular cluster systems and by extension of the galaxies of which they are members.

Large numbers of these systems have been discovered and characterized in the last 15 years or so, especially from high angular resolution imaging with *Hubble Space Telescope* and spectroscopic observations with new very large ground-based optical telescopes. While super star clusters have not yet been seen in the Milky Way or in M31, they have been discovered in large numbers in several environments: in starbursting gas-rich dwarf irregular galaxies (Melnick, Moles & Terlevich 1985, O’Connell, Gallagher & Hunter 1994, Ho & Filippenko 1996a,b, Gelatt, Hunter & Gallagher 2001, Billett et al. 2002, Vanzi 2003), in more massive starburst galaxies (Holtzmann et al. 1992, Whitmore et al. 1993, Meurer et al. 1995, Whitmore & Schweizer 1995, Zepf et al. 1999, Tremonti et al. 2001, Lipsy & Plavchan 2004, Turner & Beck 2004, McCrady et al. 2005, Melo et al. 2005), many of which show signs of recent mergers or interactions, and in the compact group Stephan’s quintet (Gallagher et al. 2001). In some of these galaxies, such as M82, NGC 4038/9, NGC 1275, etc., super star clusters incorporate a significant fraction of the starburst (Lipsy & Plavchan 2004, McCrady et al. 2005) and are preferentially found in the inner regions of the galaxy (Whitmore & Schweizer 1995, Meurer et al. 1995). Their masses are measured to be up to  $10^6 M_{\odot}$  (McCrady et al. 2005), and their metallicities range from  $[\text{Fe}/\text{H}] = -1.5$  in dwarf irregular

galaxies to several times solar in the large galaxy mergers.

NGC 3310 is a small spiral galaxy ( $M_B = -19.6$ ;  $D = 14$  Mpc, adopting the Hubble distance found using  $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ) which has a disturbed morphology both in its optical light and HI distribution (Kregel & Sancisi 2001; Mulder & van Driel 1996; de Grijs et al. 2003a,b; Wehner & Gallagher 2005), and whose inner regions underwent a burst of star formation about 30 Myr ago, with the formation of several hundred super star clusters (de Grijs et al. 2003b). The present paper describes the serendipitous discovery of SDSSJ103913.70+533029.7 (hereafter SDSS1039+53), an unresolved ( $< 1''$ ) object with a radial velocity of about  $1000 \text{ km s}^{-1}$ . Several lines of evidence suggest that it is associated with NGC 3310. If so, its luminosity, colors and spectrum point to its being a compact, high-luminosity super star cluster at a projected distance of 17 kpc from NGC 3310. By contrast, all previously-known super star clusters lie in the inner kpc or two of their parent galaxy.

The relevant details of the SDSS observations are summarized in the next section. Section 3 describes the properties and nature of SDSS1039+53. We discuss the possibility that this object is a high-velocity Galactic star, but favor the evidence associating it with NGC 3310. Under this assumption, its properties are shown to be consistent with its being a super star cluster of age similar to that of the recent merger/interaction involving NGC 3310. The SDSS imaging also confirms the presence of stellar shells around NGC 3310 (Wehner & Gallagher 2005) and shows the disturbed morphology of the galaxy. The discussion and conclusions are given in Section 4.

## 2. The Sloan Digital Sky Survey

The Sloan Digital Sky Survey (SDSS) is a 5-band photometric survey of about 10,000 square degrees of the Northern sky to a depth of about 22.5 ( $r$  magnitude, point source) and a concurrent redshift survey of up to a million galaxies and 100,000 quasars selected from the imaging survey (York et al. 2000). The SDSS camera (Gunn et al. 1998) mounted on a dedicated 2.5 meter telescope (Gunn et al. 2005) at Apache Point Observatory (APO), New Mexico, acquires imaging data in five bands,  $u$ ,  $g$ ,  $r$ ,  $i$ , and  $z$ , centered at approximate effective wavelengths of 3551, 4686, 6166, 7480 and 8932 Å (Fukugita et al. 1996). The imaging data are automatically reduced through a series of software pipelines (Lupton et al. 2001, 2003; Pier et al. 2003; Ivezić et al. 2004). The instrumental fluxes are calibrated via a network of primary and secondary stellar flux standards to  $AB_v$  magnitudes (Oke & Gunn 1983; Fukugita et al. 1996; Hogg et al. 2001; Smith et al. 2002; Tucker et al. 2005), and the absolute positions are calibrated using standard astrometric catalogues (Pier et al. 2003).

Targets for spectroscopy are selected from the imaging data on the basis of their photometric properties. As well as the primary SDSS targets (galaxies and quasars), stars in many different locations of color-magnitude space are selected to provide backup targets in regions of low galaxy density and serve as spectrophotometric standards. The target objects are mapped (Blanton et al. 2003) onto  $3^\circ$  diameter aluminum fiber plug plates which feed the spectrographs. The pair of dual fiber-fed spectrographs (Uomoto et al. 1999) can observe 640 spectra at one time with a wavelength coverage of 3800 - 9200 Å and a resolution of 1800 to 2100. The spectra are extracted from CCD images, calibrated, and corrected for sky emission and absorption. The resulting calibrated spectra are fit to a series of templates of galaxies, quasars and stars to derive the spectral classification, redshift and redshift error of each object (D. Schlegel, in preparation: see <http://spectro.princeton.edu>). Stellar templates are taken directly from SDSS spectra and calibrated with respect to spectral type and radial velocity using the ELODIE stellar library (Prugniel & Soubiran 2001; Moulton et al. 2004). The SDSS data are described in the data release papers by Abazajian et al. (2003, 2004, 2005) and Adelman-McCarthy et al. (2006) and documented at web sites listed therein and at <http://www.sdss.org>.

We examined the spectroscopic data in the SDSS archives as of January 12, 2005, selecting objects spectroscopically classified as stars. The sample was further selected by magnitude:  $g < 20$ , and by color:  $0.8 < u - g < 1.5$ ,  $g - r < 0.5$ , roughly the colors of halo turnoff stars (F subdwarfs) and horizontal branch stars (cf. Yanny et al. 2000, Newberg et al. 2002, Sirko et al. 2004a). During the selection, magnitudes were not corrected for interstellar extinction. SDSS has obtained spectra of many tens of thousands of stars with these properties; in all, 40746 spectra were found in the data base that satisfied these selection criteria. The heliocentric radial velocities of the stars were corrected to the Galactic standard of rest assuming a solar velocity of  $16.6 \text{ km s}^{-1}$  towards  $\alpha(2000) = 17^{\text{h}} 49^{\text{m}} 58.7^{\text{s}}$ ,  $\delta(2000) = +28^\circ 07' 04''$ , and a motion of the LSR of  $220 \text{ km s}^{-1}$  towards  $\alpha(2000) = 21^{\text{h}} 12^{\text{m}} 01.1^{\text{s}}$ ,  $\delta(2000) = +48^\circ 19' 47''$ . The distribution of velocities for this large sample is Gaussian with a standard deviation of  $102 \text{ km s}^{-1}$  (Sirko et al. 2004b); however, one object, SDSS1039+53, has a Galactocentric velocity well outside this range,  $+1067 \pm 19 \text{ km s}^{-1}$ , greatly in excess of the expected escape velocity from the Galaxy. Various properties of SDSS1039+53 are summarized in Table 1. Its SDSS spectrum is shown in Figure 1, and its colors, corrected for Galactic extinction using the values given by Schlegel, Finkbeiner & Davis (1998), are compared with those of a sample of stars observed by SDSS from Finlator et al. (2000) in Figure 2.

### 3. SDSS1039+53: Galactic or Extragalactic?

SDSS1039+53 was observed in two imaging runs. In both observations, the object is classified as a point source in all five bands, except for the  $u$  band image taken in poorer seeing (run 2735). In the run with better seeing (run 2821) the object is unresolved at the PSF diameter,  $0.9''$ , in the  $r$  and  $i$  bands. Its colors (Figure 2) are close to but not identical with those of halo/thick disk F/G stars. The object has no detectable proper motion; USNO-B + SDSS gives  $\mu_\alpha = 1 \pm 3.9 \text{ mas yr}^{-1}$ ,  $\mu_\delta = -2 \pm 3.9 \text{ mas yr}^{-1}$  (Munn et al. 2004).

There is only one spectrum of SDSS1039+53 in the SDSS data archives, that shown in Figure 1, and it is similar to that of a middle-F star. Thus at first glance SDSS1039+53 appears to be a star with a velocity well outside the velocity range of Galactic stars, and is the only such object so far discovered in the SDSS spectroscopic data base. Given the extraordinary value of the radial velocity, we performed a number of tests to investigate the reality of this measurement. First, the spectrum was analyzed using two different codes and template sets. Cross-correlation analysis (SubbaRao et al. 2002) gives a heliocentric velocity of  $1028 \pm 23 \text{ km s}^{-1}$ , while a direct  $\chi^2$  minimization fit (D.J. Schlegel, unpublished) gives  $1012 \pm 19 \text{ km s}^{-1}$ . The use of different templates, with types from late B to F, produces a scatter of about  $10 \text{ km s}^{-1}$ , and fitting a polynomial to the centers of the Balmer lines gives  $1009 \pm 9 \text{ km s}^{-1}$ . Second, the spectrum is actually the composite of two spectra, measured by the red and blue spectrographs. Both yield the same radial velocity. Third, there are five stars on plate 1010 which are also observed on other plates, and the measured radial velocities agree to within the errors. In total, there are 30 stars in the selected color and magnitude range observed in plate 1010 in addition to SDSS1039+53, and the measured velocities span the range  $-140 \text{ km s}^{-1}$  to  $+213 \text{ km s}^{-1}$ . Fourth, the sky spectrum was examined. Figure 1 shows the sky spectrum in the region 5400 to 6000 Å, where very strong night-sky emission from the Na D lines and the [OI]  $\lambda 5577$  airglow lie. Were there an error in the wavelength calibration of the spectrum of SDSS1039+53, the night sky subtraction would show very large residuals in this wavelength region, when in fact there is no discernable residual at NaD and only a small residual at 5577 Å.

A final, and definitive test was supplied by a spectrum obtained with the Marcario Low Resolution Spectrograph (Hill et al. 1998) on the Hobby-Eberly telescope on 14 February 2005. This spectrum, which covered the H $\alpha$  line at a resolution of approximately 1000, yields a heliocentric radial velocity of  $1033 \pm 70 \text{ km s}^{-1}$ , consistent with the results from the SDSS data.

Therefore, SDSS1039+53 could be a Galactic high-velocity star, like that recently discovered by Brown et al. (2005). Several methods were used to derive the stellar parameters

under this assumption. Fitting the flux-calibrated spectrum to synthetic spectra based on Kurucz (1979, 1993) model atmospheres using the methods of Allende Prieto et al. (2005) gives:  $T_{\text{eff}} = 6237 \pm 247$  K,  $\log g = 2.00 \pm 0.26$ ,  $[\text{Fe}/\text{H}] = -0.37 \pm 0.17$ , and badly overestimates the strength of the Ca II K line. The techniques described by Wilhelm et al. (1999) yield:  $T_{\text{eff}} = 6456$  K,  $\log g = 2.27$ , and  $[\text{Fe}/\text{H}] = -2.44$ , with the abundance derived primarily from the CaII K line. Other metal lines give a much higher value,  $[\text{Fe}/\text{H}] = -0.71$ . The spectrum and colors are consistent with classification of SDSS1039+53 as a horizontal-branch star at 60 kpc. However, the line widths for H $\epsilon$  and H $\delta$  are much larger than that of H $\gamma$ . Finally, the abundance obtained using the Beers et al. (1999) calibration of the CaII K line and the colors is  $[\text{Fe}/\text{H}] = -1.88$ . Taken as a whole, these results suggest that the spectrum of this object is composite, which might be expected if it is not a single star, but the integrated light from a cluster of stars.

If, on the other hand, SDSS1039+53 is extragalactic, as suggested by its radial velocity, its very compact light distribution (with an inferred diameter of  $\leq 40$  pc) suggests two possible interpretations: it may be a compact dwarf galaxy, like those formed by tidal disruption in clusters (Drinkwater et al. 2003, Hasegan et al. 2005), or a star cluster like those seen in starburst galaxies. SDSS1039+53 does not lie in a cluster of galaxies, but is about 4.1' from the Sbc galaxy NGC 3310, which has a very similar radial velocity,  $V_{\text{helio}} = 993$  km s $^{-1}$ . Further, NGC 3310 itself is a galaxy which has recently undergone a merger with one or more gas-rich systems: it has extensive HI tidal tails and is surrounded by a low surface brightness shell system (Kregel & Sancisi 2001; Wehner & Gallagher 2005). Thus the more likely interpretation is that SDSS1039+53 is a compact star cluster associated with NGC 3310.

#### 4. Discussion and Conclusions

NGC 3310 is at a distance of about 14 Mpc and is a “minor merger”, with extended HI tidal tails (Kregel & Sancisi 2001), stellar shells surrounding the main disk (Wehner & Gallagher 2005) and a large-scale starburst in its inner regions (de Grijs et al. 2003b) which is considerably younger than the inferred age of the merger (see below). The SDSS image of this galaxy and its surroundings is shown in Figure 3. Tidal shells can be seen, as well as the actively star-forming spiral arms which have a distorted and chaotic morphology. The image also shows SDSS1039+53, at a distance of 4.14 arcminutes from the center of NGC 3310. The coincidence in velocity and sky position strongly suggests that these two unusual objects are associated. If so, the absolute magnitude of SDSS1039+53 is  $M_r = -11.3$  ( $M_V \sim -11.2$ , using the conversions given by Fukugita et al. 1996). This luminosity is much higher

than those of the Galactic globular clusters (cf. Peterson 1993 and Djorgovski 1993) but is similar to those of super star clusters.

What is remarkable about SDSS1039+53 is its distance from the galaxy nucleus (4.14 arcminutes, 17 kpc). Meurer et al. (1995) note that super star clusters are typically found “at the very heart of starbursts”. In their ultraviolet imaging survey, over 90% of super star clusters were found where the local surface brightness was within 1.5 magnitudes  $\text{arcsec}^{-2}$  of its peak value. SDSS1039+53, in contrast, is well outside the optical extent of NGC 3310 as seen in Figure 3, and considerably beyond the de Vaucouleurs radius ( $R_{25} = 1.55$  arcmin, de Vaucouleurs et al. 1991). The cluster’s projected distance is equivalent to  $\sim 20$  disk scale lengths ( $r_0(I) = 12.4 \text{ arcsec} = 0.84 \text{ kpc}$ , Sánchez-Portal et al. 2004). This would be untypical – but not unheard of – for a globular cluster; roughly 95% of the Milky Way’s globular clusters are found within  $\sim 10r_0$  ( $r_0 = 2.8 \text{ kpc}$ , Ohja 2001), with the most distant globular cluster lying at  $42 r_0$ , 117 kpc (Harris 1996).

To determine an age for the star cluster we fit Bruzual & Charlot (2003) simple stellar population models (SSPs) to both the optical spectrum and to the SDSS *ugriz* colors (both the spectrum and colors were corrected for Galactic foreground reddening and extinction using the maps of Schlegel, Finkbeiner & Davis 1998). Because the cluster lies so far outside the optical and HI disk of NGC 3310, we assumed no intrinsic reddening. We adopted a metallicity of  $Z = 0.008$  (60% solar) since this is in good accord with the nebular abundances in HII regions outside the nucleus (Pastoriza et al. 1993) and with metallicities derived for star clusters from *HST* multiband photometry (de Grijs et al. 2003b). We compared the data to a grid of 110 models with ages ranging from 10 Myr to 1 Gyr. The  $\chi^2$  evolution of the models along with the best fits are shown in Figure 4. The optical spectrum is fit over the full wavelength range available, 3800 - 9200 Å. The best-fit spectrum has an age of 570 Myr. The photometry provides additional information, because the SDSS spectra do not cover the *u* and *z* bands; the photometry alone fits best to an SSP model of age 720 Myr. These two independent fits provide some measure for the systematic uncertainties in the SDSS photometry and spectroscopy, and give a cluster age of  $700 \pm 150$  Myr. The model cluster mass is  $1.4 \times 10^6 M_\odot$ , assuming a Chabrier (2003) Galactic Initial Mass Function (a Salpeter IMF extending down to  $0.1 M_\odot$  would increase the mass estimate by a factor of 1.4).

The derived age and mass of SDSS1039+53 place it squarely in the régime of super star clusters (age  $\lesssim 1 \text{ Gyr}$ , mass =  $10^5 - 10^8 M_\odot$ , O’Connell 2004). However, when compared to the inner disk cluster population in NGC 3310, SDSS1039+53 stands out as being both relatively old and massive. de Grijs et al. (2003a,b) characterized the cluster population in the inner 33 arcseconds of NGC 3310 using multi-band *HST* photometry. Out of 174

clusters, they find only a few percent with  $M \sim 10^6 M_\odot$  and roughly 10% with ages  $> 100$  Myr. Only one cluster satisfies both criteria. The mean age of the cluster population is around 30 Myr, and de Grijs et al. suggest a burst duration of 40 Myr. Thus SDSS1039+53 is considerably older than the most recent starburst event in the galaxy disk.

NGC 3310 is surrounded by shells and tidal debris (see Figure 3) and recent observations have found additional features extending to distances of about 15 kpc from the galaxy. Kregel & Sancisi (2001) observed HI tails to the north and south of the galaxy, while Wehner & Gallagher (2005) find a faint stellar arc to the north and east. These observations suggest an age for the encounter which produced the faint stellar arc of about 0.5 Gyr, close to the age inferred for SDSS1039+53. The position of SDSS1039+53 lies close to that of the faint outer stellar arc - near feature “N” in Figures 2 and 4 of Wehner and Gallagher (2005). (This feature has a surface brightness of  $\mu_V = 22.55$  mag arcsec<sup>2</sup> and is not visible in the shallower SDSS images). Wehner & Gallagher (2005) suggest that the outer stellar arc is tidal debris from a disrupted dwarf companion. However, our finding of a comparatively young cluster in this location suggests that the faint light could be composed of stars formed in the merger event. Obtaining accurate colors for the faint light should help clarify this situation. Although it is not necessary to invoke formation of SDSS0139+53 at this location – had it formed in the center of the galaxy it would have needed an average velocity in the plane of the sky with respect to the galaxy of only 35 km s<sup>-1</sup> to reach its present location – its properties identify it with the merger event which took place in NGC 3310 and identify it as a young globular cluster associated with and formed from the far-flung debris of the merger.

While most of the super star clusters found to date in starburst dwarfs and merging galaxies are in the inner regions of the galaxies, it is also the case that for almost none of these galaxies have the surroundings been searched. Yet star formation has been observed well outside the optical disks in a small number of galaxies. For example, Hibbard et al. (2005) identify star formation in the tidal tails of the Antennae (NGC 4038/9) in GALEX images; small HII regions have been discovered at distances as large as 30 kpc from their galaxy (Ryan-Weber et al. 2004), and in most of the cases discussed in that paper there is evidence for tidal disturbance of the associated galaxy; and HST imaging shows star clusters and dwarf galaxies in the tidal tails of merger galaxies which are themselves undergoing intense star formation (Knierman et al. 2003; Tran et al. 2003; Bastian et al. 2005). Thus it is possible that there are many more super star clusters at large distances from NGC 3310 – the field (Figure 3) contains several more sources of bluish color – and that young globular cluster systems can be identified around this and other galaxies.

Finally, we compare SDSS1039+53 with SDSS090745.0+024507, the hyper-velocity star



discovered by Brown et al. (2005). As Figure 2 shows, SDSS0907+02 is much bluer than SDSS1039+53, with the colors of a young star. Further, there are no plausible host galaxies within many degrees. Thus unlike SDSS1039+53, the observational data for SDSS0907+02 strongly support the interpretation of Brown et al. (2005): that it is a star escaping the Galaxy. So far, SDSS spectroscopy has not revealed any more hyper-velocity Galactic stars.

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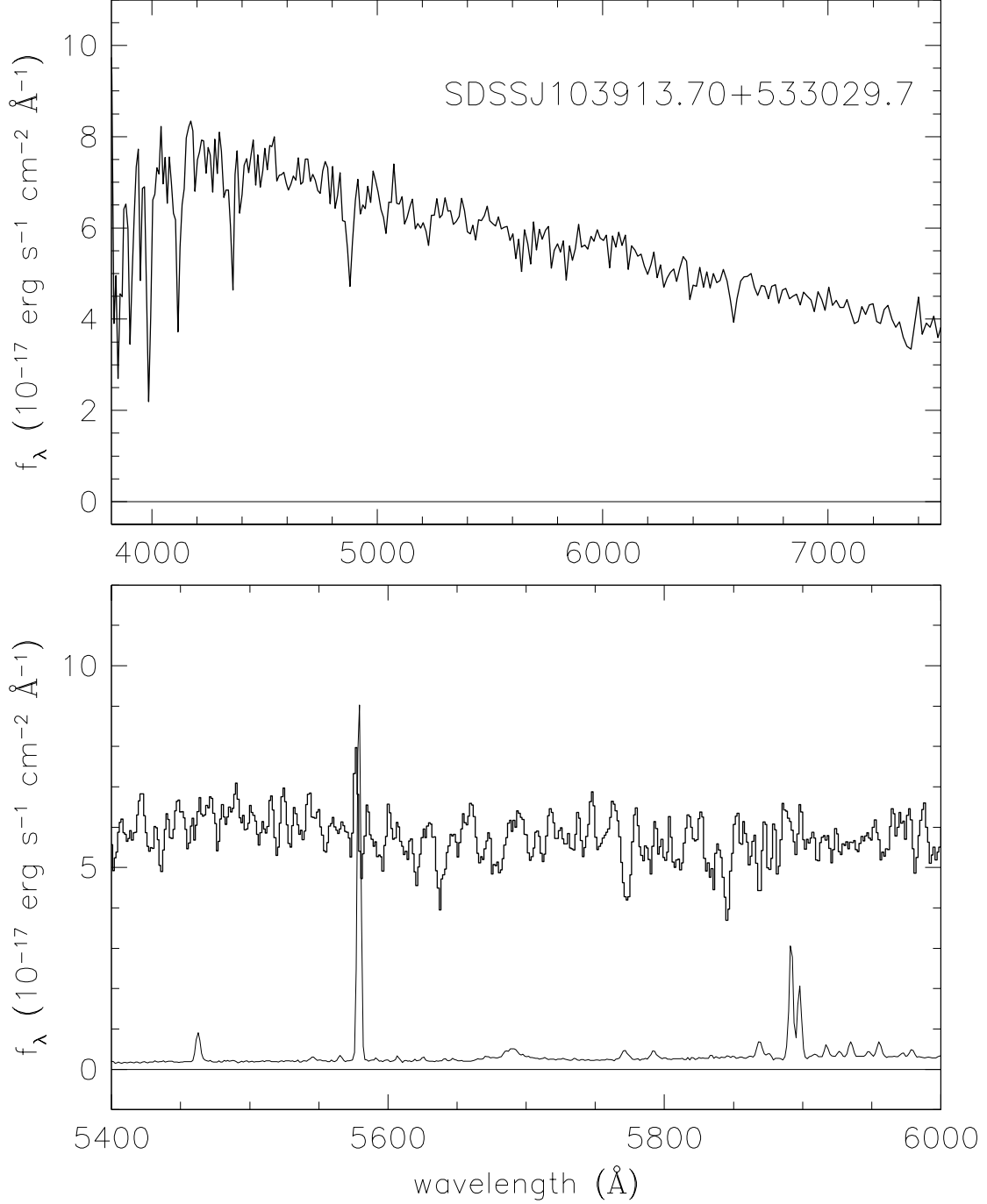


Fig. 1.— SDSS spectrum of SDSS1039+53; the spectral resolution is  $\approx 2000$ . Lower panel: expanded region of the spectrum near the atmospheric HgI 5460, [OI] 5577 and NaI D lines. The light line shows the sky spectrum, where these lines are observed at the rest wavelengths. The spectrum is from plate 1010, fiber 335, MJD 52649, and is available at the SDSS DR3 website (<http://www.sdss.org>).

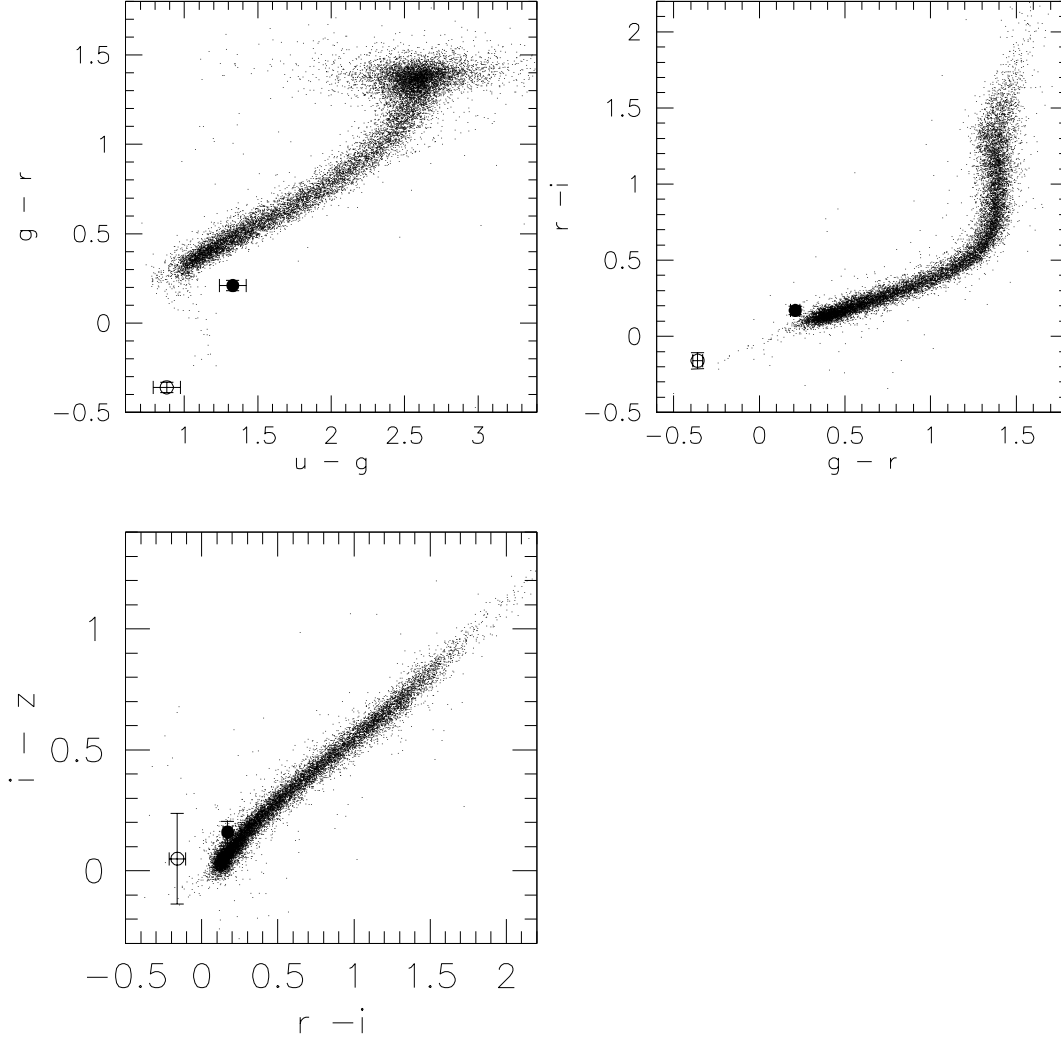


Fig. 2.— SDSS color-color plots. The dots show the colors of a sample of  $\sim 15,000$  anonymous stars measured by SDSS (see Finlator et al. 2000). The large filled symbol shows the colors of the super star cluster SDSS1039+53 and the open symbol the colors of SDSSJ090745.0+024507, the hyper-velocity Galactic star described by Brown et al. (2005) (see text for discussion). Note that the colors of SDSS1039+53 are similar, but not identical, to those of F stars.



Fig. 3.— Color composite image of NGC 3310 and its environment from SDSS imaging. The image is a composite of the SDSS  $g$ ,  $r$  and  $i$  images made using the color weighting scheme described by Lupton et al. (2004) and measures  $13.6' \times 9.2'$ . Roughly, north is up and east to the left: the image is tilted at a position angle of about  $-20^\circ$ . The super star cluster SDSS1039+53 is to the left of the galaxy and is indicated by an arrow. The faint red streak running down the left of the image is due to a 5th magnitude star to the north of the field. The color mapping is such that  $H\alpha$  is green and  $H\beta + O[III]\lambda 5007$  is blue, showing the presence of star forming regions. Note the disturbed spiral arms and the inner ring of intense star formation.

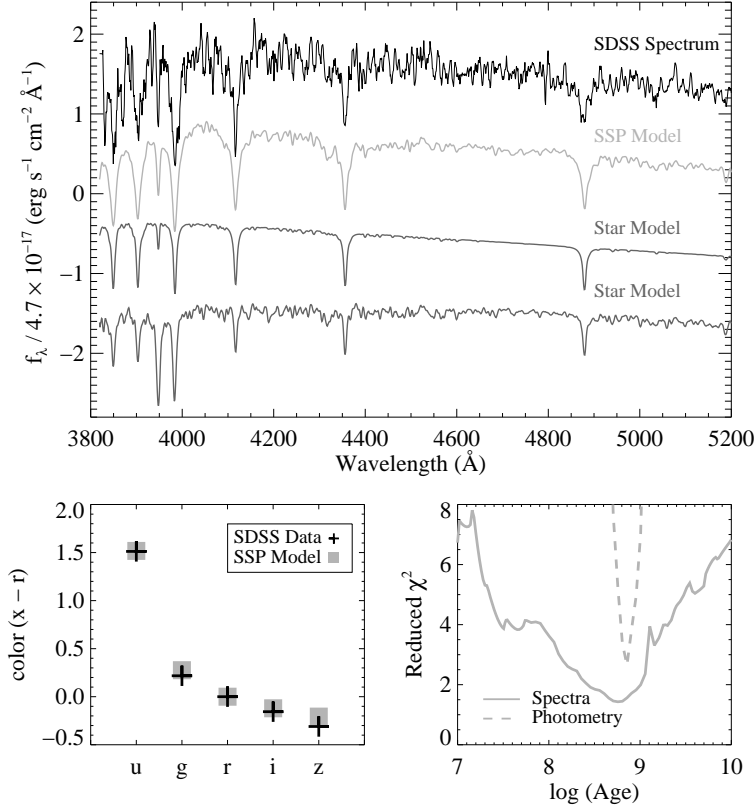


Fig. 4.— Model fits to SDSS1039+53. The upper panel contrasts the SDSS spectrum with the best fitting Simple Stellar Population (SSP) model, and two stellar models. The SSP model is from Bruzual & Charlot (2003) and has an age of 570 Myr and  $Z = 1/4 Z_{\odot}$ . The stellar models are from Kurucz (1993) and have  $T_{eff} = 6500$  K,  $[Fe/H] = -2.5$ ,  $\log(g) = 2.25$  (upper), and  $T_{eff} = 6250$  K,  $[Fe/H] = -0.5$ ,  $\log(g) = -2.0$  (lower). Both the data and the models have been boxcar smoothed by 5 pixels. The SSP model provides a considerably better fit to the the Ca K line at 3934 Å. The lower left panel compares the SDSS photometry with the best fitting SSP model. The error bars on the colors of SDSS1039+53 are smaller than the data points. The lower left panel shows the evolution of the reduced  $\chi^2$  of the fits to both the SSP spectrum (solid) and the SSP photometric data (dashed). The two independent fits provide some feel for the systematic errors. We estimate the cluster age to be  $700 \pm 150$  Myr.

Table 1. SDSSJ103913.70+533029.7

$\alpha(\text{J2000})$	$10^{\text{h}} 39^{\text{m}} 13.70^{\text{s}}$
$\delta(\text{J2000})$	$+53^{\circ} 30' 29.7''$
$v_{\text{helio}}$	$1012 \pm 19 \text{ km s}^{-1}$
$v_{\text{GSR}}$	$1067 \pm 19 \text{ km s}^{-1}$
$u$	$20.90 \pm 0.09$
$g$	$19.57 \pm 0.02$
$r$	$19.36 \pm 0.02$
$i$	$19.19 \pm 0.02$
$z$	$19.03 \pm 0.04$

Note. — The magnitudes are corrected for interstellar extinction using the data of Schlegel, Finkbeiner & Davis (1998).

This figure "figure3.jpg" is available in "jpg" format from:

<http://arXiv.org/ps/astro-ph/0511010v1>